Trends in
Cognitive Sciences

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Spotlight

The ebb and flow of cognitive fatigue

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If you are currently feeling tired, you are not alone: feelings of fatigue are incredibly common. In a recent study, Matthews *et al.* investigated moment-to-moment fluctuations in fatigue using behavioral experiments and computational modeling. The study offers a precise account of how fatigue waxes (during physical and cognitive effort) and wanes (during rest).

Whether in health or disease, almost all people are familiar with the feeling of fatigue. In healthy people, fatigue often emerges after physical or mental work. For them, fatigue is (at least mildly) unpleasant and demotivating, but reversible: it diminishes with rest. At the same time, fatigue is a common symptom of many mental and physical syndromes and illnesses, such as burnout, depression, diabetes, long COVID, and cancer. For people living with these conditions, fatigue can make even the most mundane activities, such as writing an email, feel like a mountain to climb.

There are reasons to think that the prevalence of fatigue will rise over the coming decades. Disorders characterized by fatigue are attributable, in part, to lifestyle factors, such as obesity, which show an increasing trend. In addition, somewhat counter-intuitively, technological progress tends to increase the mental demands of work. This is because routine tasks are often automatized first, leaving non-routine cognitive tasks for humans [1]. Thus, fatigue is here to stay.

Despite its prevalence, fatigue, especially cognitive fatigue, is poorly understood. On an optimistic note, there is an emerging consensus about the function of cognitive fatigue, which could be described as the *adaptive signal hypothesis*. This hypothesis holds that fatigue is an evolved signal that aids decision making. Specifically, fatigue indicates that one's current activity (e.g., working on a spreadsheet in the office) has lower utility than the next-best alternative (e.g., chatting with colleagues) [2]. In turn, fatigue, an adaptive signal, biases people toward switching to this alternative activity [3]. Often, this is an activity that is less effortful compared with the current task.

On a pessimistic note, despite ~120 years of research, there is no mature theory of the origins of cognitive fatigue [4]. A key problem is that fatigue is often treated as though it were a static quantity. To illustrate: in medicine, to measure fatigue, patients are often asked how tired they 'usually' feel or how tired they have felt 'lately' [5]. Thus, research typically does not capture meaningful variation in fatigue over the course of a day. Similar static approaches are common in psychology (e.g., in research on burnout). Yet, fatigue is a dynamic phenomenon (Figure 1). Fatigue waxes and wanes over time, within and across days. It follows idiosyncratic rhythms that are, due to the limitations of our current paradigms, largely unexplored.

In a new paper, Matthews *et al.* [6] examined the dynamics of physical and cognitive fatigue. In one experiment, which lasted ~1 h, participants repeatedly made decisions to exert physical effort (squeezing a handgrip; for a large reward) or to rest (for a small reward). After each period of effort or rest, which always lasted ~6 s, participants rated how tired they felt. A second experiment mirrored the first, except that it focused on cognitive effort. Here, participants repeatedly made decisions about whether to engage in effortful arithmetic (for a large reward) or to rest (for a small reward). This study design allowed Matthews *et al.* [6] to model how fatigue waxes (during physical and cognitive effort) and wanes (during rest).

A key insight from this work is that there are important parallels between physical and cognitive fatigue. Specifically, for both types of fatigue, the best-fitting computational model parsed fatigue into two components: a recoverable component (i.e., the share of fatigue that increases with effort and recovers with rest) and an unrecoverable component (i.e., the share of fatigue that only increases with effort and does not recover with rest, at least not within the ~1-h session). For physical fatigue, this result conceptually replicates a previous study [7]; for cognitive fatigue, this result is new and original. Together, these findings paint a nuanced picture of how both physical and cognitive fatigue emerge over time. From an applied angle, the distinction between recoverable and unrecoverable fatigue is intriguing: it has potential implications for task design, such as in the contexts of education and work.

Another key insight from the paper is that cognitive fatigue responds to people's previous errors. Specifically, cognitive fatigue showed the steepest increase during trials in which people exerted effort but were unsuccessful. In line with the adaptive signal hypothesis, this finding suggests that, when people feel they are not performing well despite exerting effort, they get more fatigued.

Given that the latter finding applied only to cognitive fatigue, not physical fatigue, one may be tempted to conclude that the two types of fatigue are underpinned by distinct mechanisms after all. However, this conclusion would be premature because people made only few errors on the physical task; thus, it remains unclear how errors

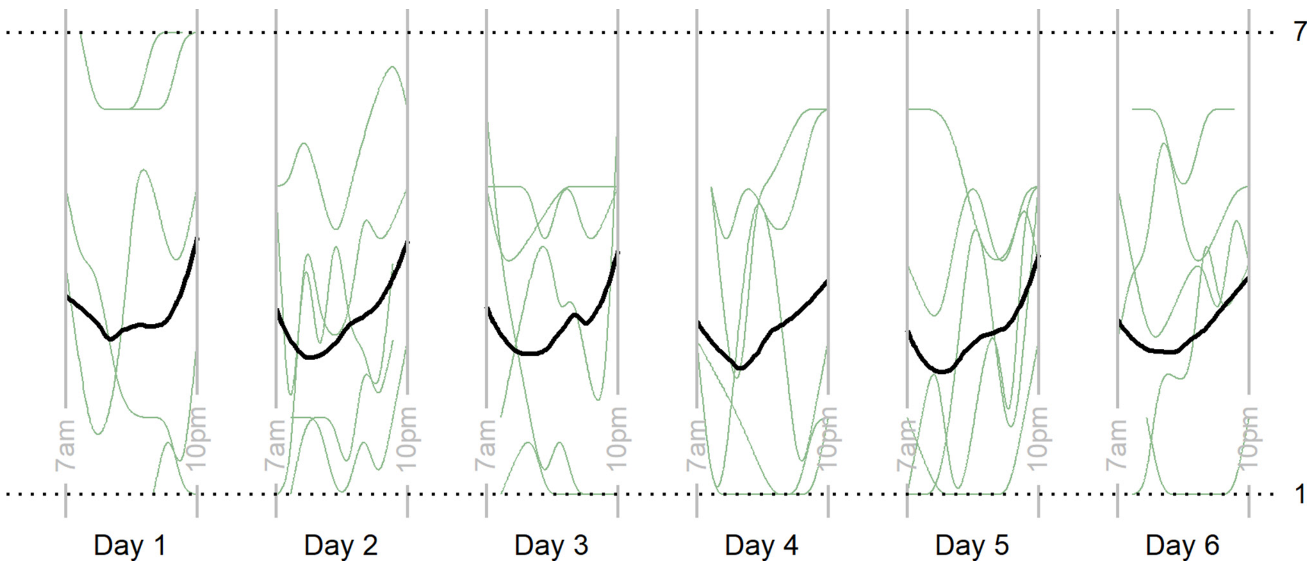

Figure 1. Temporal dynamics of fatigue. In the Healthy Brain Study [11], healthy adults reported their fatigue level for 6 consecutive, regular days, up to ten times per day, on a 1–7 scale. Average time courses of fatigue (thick black lines; based on N = 100) suggest that, at the group level, fatigue follows a predictable, daily recurring pattern. However, individual trajectories (thin green lines; each line represents N = 1, randomly selected) suggest that the dynamics of fatigue vary widely between individuals.

affected physical fatigue. More broadly, prior research shows that there is substantial overlap between physical and cognitive fatigue. For example, in a recent experiment, a physical effort manipulation increased not only physical, but also cognitive, fatigue and vice versa [8]. On balance, physical and cognitive fatigue may be more similar than they are different.

An intuitive next step would be to study the dynamics of fatigue across longer time courses (e.g., several days) and in real-life settings [9]. Fatigue plausibly emerges from a range of biological, psychological, social, and societal systems, which interact in various ways, on various timescales. Thus, fatigue can be conceptualized as an emergent phenomenon of a complex dynamic system. This conceptualization comes with a new lens to look at fatigue. Rather than trying to isolate the causes of fatigue in a reductionistic manner (which is the current norm), it may be better to examine the biopsychosocial context in detail, while modeling the dynamics of fatigue. For example, future research could apply computational modeling to examine how fatigue ebbs and flows in real life, such as to understand the impact of work characteristics, social relationships, or viral infections. This research could draw from modern theories of psychopathology, which also emphasize fluctuations in symptoms over time [10].

In sum, fatigue is widespread, unpleasant, and is not going away. It is a dynamic phenomenon and Matthews *et al.* [6] showed that it is insightful to treat it as such.

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Declaration of interests

The author declares no competing interests.

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